Chapter 7
Sewer Sediment Flushing - A Case Study

Introduction
This chapter describes a case study aimed at assessing the cost-effectiveness of sewer flushing technology from different performance perspectives. These performance perspectives are minimization of maintenance costs, reduction of sediments CSO "first-flush", and reduction of sediments to lower H_2S levels. This case study uses information developed from Fresh Pond Parkway Sewer Separation and Surface Enhancement Project in Cambridge, Massachusetts (Pisano et al., 2001). Grit deposition within both domestic sewerage and storm drainage systems is a major problem because of general flatness of the area. Presence of several shallow streams that the sewerage (storm and sanitary) systems must cross under as siphons, and the hydraulic level of the receiving water body that frequently backwaters the storm systems. To overcome this problem in the area, automated flushing systems using quick opening (hydraulic operated) flushing gates to discharge collected stormwater will flush grit and debris to downstream collector grit pits.

Over the last twenty years, the City of Cambridge has enhanced drainage service for improving the water quality in the Alewife Brook and the Charles River. This area is north and west of Harvard Square and within dense heavily traveled urban regions.

Background Characteristics

Fresh Pond Parkway Sewer Separation Project
Over the last twenty years, the City of Cambridge has separated old combined systems to sanitary and storm sewerage systems throughout the city to enhance drainage service and to improve the water quality in the Alewife Brook and the Charles River. Presently, the City is in the construction phase of separating a 100 ha (250 acre) catchment North and West of Harvard Square within a highly urbanized and heavily traveled area.

Grit deposition within both existing sewerage and storm drainage systems is a major problem because of general flatness of the area, presence of several shallow streams that the sewerage (storm and sanitary) systems must cross then streams under as siphons, and the hydraulic level of the receiving water body that frequently backwaters into the storm systems. The existing and recently constructed storm drains on Fresh Pond Parkway and Concord Avenue have invert slopes of approximately 0.0003 to 0.0005. Deposition of any residual stormwater solids not captured by the surface best management practices (BMPs) that discharge into these conduits would be severe. Since no chemical salting during winter conditions can be tolerated in the low, flat Fresh Pond Reservation watershed, heavy winter sanding only exacerbates potential deposition problems. Figure 5 depicts the Wheeler Street storm drain, which is the wet-weather flow outlet from the catchment area. Sediment deposition was observed up to the spring line of the conduit.

Figure 5. Wheeler Street 2.8 m Storm Drain Sewer Half Filled with Sediments

To overcome this problem, automated flushing systems, using quick opening (hydraulically operated) flushing gates to discharge collected stormwater, will flush grit and debris to downstream collector grit pits (either sumps in the flush vault structure or manholes). Grit pits will not be provided on the sanitary systems being flushed. The storm and sanitary sewer systems to be flushed are within the Fresh Pond Parkway near the Cambridge Water Treatment Plant (CWTP), continue East to Concord Circle and then northeast to the Fresh Pond Circle. Both systems then proceed down Wheeler Street. Figure 6 shows the locations of the sanitary sewer and storm drain flushing vaults. The piping systems consist of approximately 1000 m (3280 ft) of sanitary trunk sewers, ranging from 460 mm to 600 mm (18 in. to 24 in.), and approximately 1620 m (5314 ft) of existing storm drains with pipe sizes ranging from 900 mm to 1.2 m by 1.8 m (36 in. to 4 ft by 6 ft.)

Description of Piping Systems to be Flushed

The storm and sanitary sewer systems to be flushed are located within the catchment area. These systems start on the Fresh Pond Parkway near the Cambridge water treatment plant, continue East to the Concord Circle and then Northeast to the Fresh Pond Circle. Both systems then proceed down Wheeler Street under the Massachusetts Bay Transportation Authority - Conrail railroad tracks and terminate near the Alewife Parking Garage. The piping systems consist of approximately 555 m (1820 ft) of sanitary trunk sewers, ranging from 460 mm to 600 mm (18 to 24 in.), and approximately 1620 m (5314 ft) of existing storm drains with pipe sizes ranging from 975 mm (24 in.) to 1.52 m by 1.83 m (5 ft by 6 ft). Figure 6 shows the general locations of the flushing vaults.

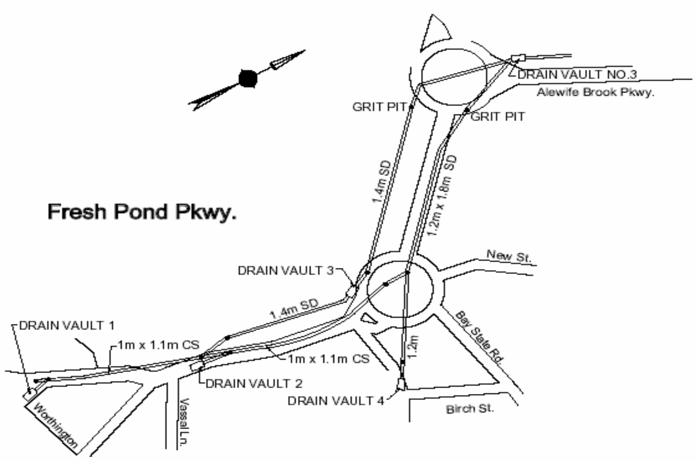

Figure 6. Fresh Pond Parkway – Locations of Flushing Vaults

Description of Flushing Vaults
Another alternative is to retain pipes with flat slopes, but provide periodic cleaning of these pipes by automatic passive means to maintain hydraulic capacities. The use of flushing chambers at specific locations, with grit pits downstream was designed for the Fresh Pond Project. The design utilized quick opening flushing gates (hydraulically driven) that release stored water to create a "dam break" flush wave to cleanse and move sediments downstream to a grit pit.

Figure 7 shows a typical storm sewer-flushing chamber with quick opening gate designed for the City of Cambridge. The Fresh Pond Parkway flushing gate chamber is shown in Figure 8. During a rainfall event, stormwater from the incoming storm drain fills the sump adjacent to the flush chamber. Then stormwater is pumped from the sump into the flush chamber. Each flush chamber volume was sized based on the roughness, slope, size and length of the pipe being flushed. The "flush wave" is designed to have a depth of approximately 75 to 100 mm (3 to 4 in.) and a velocity range between 0.5 to 0.75 m/s (1.6 to 2.5 ft/s) at the end of the pipe segment being flushed.

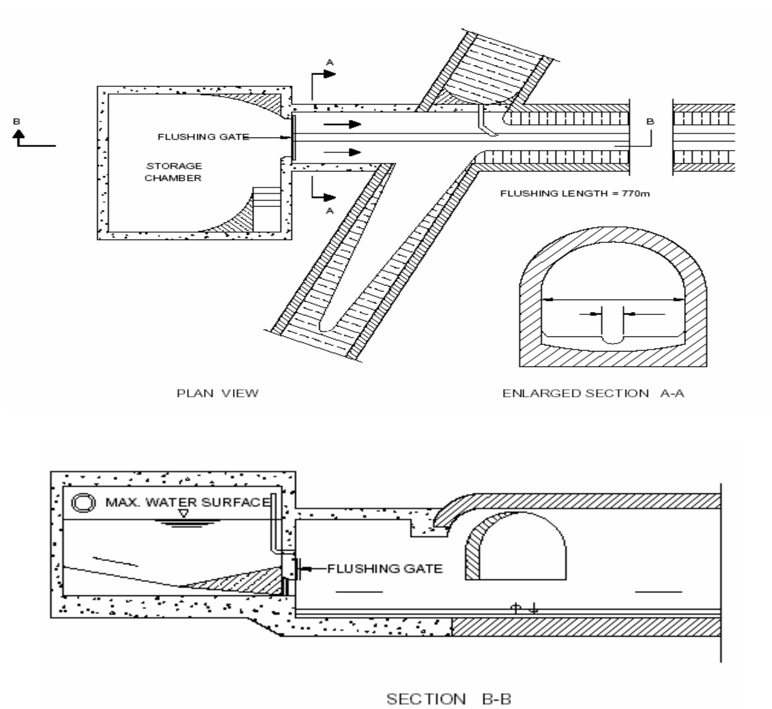

Figure 7. Flushing Storage Configuration with Flushing Gate Installation

Process water (back wash) from the new Cambridge Water Treatment plant will be pumped to the new sanitary system and collected in sanitary sewer flushing vaults and used for periodic flushing of the sanitary sewers. This approach is intended to minimize the daily operation of the system and provide the flexibility of cleaning the pipes on demand. It would be cost-effective, due to reduced initial capital costs and minimal long term operational and maintenance costs versus a typical pumping station that requires daily maintenance and power.

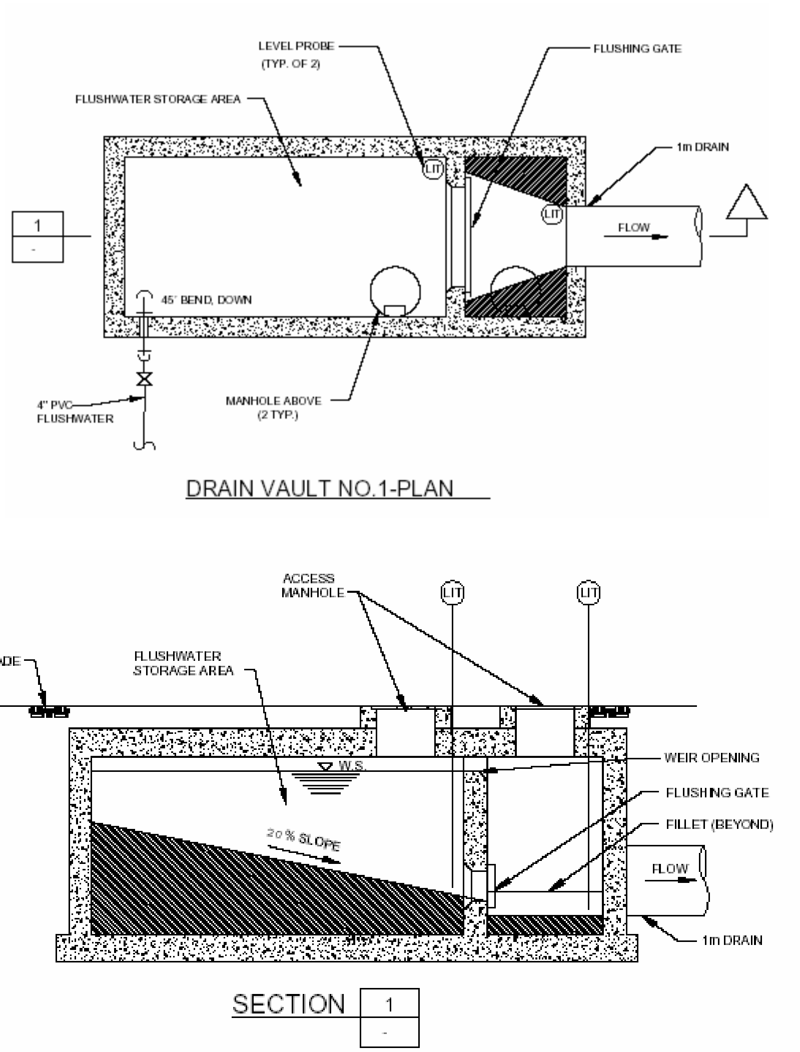

Figure 8. Fresh Pond Parkway – Flushing Gate Chamber

Physical Site Constraints
The design problems in separating the existing combined sewer system, increasing the level of drainage service from 1 yr to 10 yrs, and providing a means to routinely flush the sanitary and storm drainage system were included in the following:

The Fresh Pond Parkway in this area consists of four lanes conveying 30,000 to 50,000 vehicles per day with several rotaries having multiple directional ingress pathways. The Parkway has been historically a utility corridor for 17 other major electric, telephone, communication, gas, and water supply conduits. The inverts of both the sanitary and combined sewers are nearly the same as the sanitary system. Effective sewer separation mandated re-laying new sanitary trunk systems to permit cross connections. Traffic management was horrific as major commercial enterprises had direct access to the Parkway and had to be maintained.

Design Process

At the onset of the design in mid 1997, the flushing volumes for the storm drain vaults noted in Table 26 were developed. The design information regarding pipe size, roughness, shape, slope, and the distance between the proposed flushing vault and the downstream receiving pit (i.e., the flushing length that requires sediment transport), were provided. These volumes were then adjusted upwards where feasible to account for uncertainty, expected high amount of sand used during winter operations on Fresh Pond Parkway, and the extreme space limitations, imposed by other utilities within the Fresh Pond Parkway. It is noteworthy that 17 other utilities share the same four-lane corridor. Flushing volumes for the sanitary sewers were also upsized. Over the course of the final design and during construction, pipe sizes, slopes and alignments were field modified due to the complexity of existing utilities in the streets. At the onset of design, as-built horizontal and vertical alignments of utilities were only partially known. However, the initial flush volumes remained unchanged. The final piping configuration and flushing volumes were reanalyzed by the flushing gate vendor in mid 2001 and were deemed adequate and sufficient.

Table 26. **Flush vault design information summary**

Location	Downstream Flushed Pipe Size (m)	Flushing Pipe Length (m)	Flush Water Volume (m^3)
Drain Vault #1	0.98, 1.37	393	12.1
Drain Vault #2	0.98 ,1.07	216	12.5
Drain Vault #3	1.37	220	12.2
Drain Vault #4	1.22, 1.22 by 1.83	343	13.8
Drain Vault #5	1.85 by 1.52, 1.83	472	44.6
Sanitary Vault #1	0.46	201	9.6
Sanitary Vault #2	0.60	350	7.3

Proprietary flushing volume sizing rules have been developed in Germany based on a combination of physical modeling, mathematical modeling and empirical visual observations of prototype pipe flushing installations using rapid opening flush gate and other conventional more slowly opening valve schemes. The salient feature of the flushing gate technology is the ability of the gate to be instantly unlatched, to fully open, and to create flush wave with initial velocities. Typical gate opening times are 0.1 s with releasing the retained water within 10 s. The initial gate opening is best characterized as a hydraulic “dam break.”

Justifications for providing flushing systems for the new 600 mm sanitary trunk sewer system are provided in Table 27. Average peak dry weather and peak infiltration flow velocities throughout most of the year excluding inflow periods will not approach 1 m/s (3.28 ft/s) as a limit. Peak daily velocity and shear stress conditions for the upstream 450 mm (18 in.) sanitary trunk sewer are less than the estimates provided for the downstream 600 mm (24 in.) sanitary sewer noted in Table 27.

In addition to the low discharge velocities, the domestic waste tributary to the Fresh Pond Parkway and Concord Avenue sanitary system is unusual for two reasons. First, the waste contains high quantities of fats, oils and grease (FOG) discharged into the sewers from the numerous restaurants in the catchment. While a rigorous FOG program is in place, complete control is not possible. Grease buildups have been a significant problem and are expected to continue. Second, the new CWTP disposes (by permit) filtration backwash process waste on a daily basis into the sanitary sewer system. High levels of silt, soils and larger sized inorganic material within a congealed matrix of coagulants and other flocculation aids will be disposed into the sewer system on a daily basis. Since the new sewers are flat in the area, significant deposition problems exacerbated by the combination of FOG and CWTP process wastes are expected.

Table 27. Design flow and velocity evaluation for 600 mm sanitary trunk sewer

Measured Flows (11 months)	Flow (L/s)	Velocity (m/s)	Shear Stress (N/m^2)
Peak Daily Dry Weather Flow	79	0.73	1.8
Average Yearly Dry Weather Flow	37	0.58	1.3
Average Summer Dry Weather Flow	28	0.56	1.1

The design basis for the self-cleansing of the storm drain system assumed that the peak flow velocities for the 3-month storm should exceed 1 m/s (3.28 ft/s). The USEPA Stormwater Management Model (SWMM) was used to simulate system flows for the trunk sewers for the regional 3-month storm having a peak hourly intensity equal to 10 mm/hr (0.4 in./hr) with a total rainfall depth of 50 mm (2 in.). The results indicated that peak velocities for the new storm drain system consisting of existing drains, rehabilitated combined sewers or new drains (box culvert) designed to handle up to a10-year storm having peak intensity of 58 mm/hr (2.28 in./hr) did not exceed 0.5 m/s (1.64 ft/s). Flow velocities for lesser, more frequent storms will be even smaller and more problematic with respect to solids deposition. Automated flushing systems with downstream grit collection were therefore provided.

Hydraulic Modeling Simulation of Flushing Technology

The Stormwater Management Model (SWMM) with Extended Transport Block (EXTRAN) was used to investigate the efficiency of the flushing technology. Simulation output takes the form of water surface elevations and discharge at selected system locations. Computed results are only approximate since EXTRAN does not model the “dam break” phenomenon inherent to the flush gate technology. EXTRAN was developed by the USEPA and is described in total in the User’s Manual (Huber and Dickinson, 1988). The SWMM model was used to evaluate pipe-flushing facilities in Germany and for the Fresh Pond Parkway Sewer Separation Project in Cambridge, Massachusetts. The evaluation results for the German facilities have been reported elsewhere (Pisano, et al., 1998) and have been reported here for completeness.

Evaluation of Systems in Cambridge

The basic conveyance element input data required in EXTRAN are specifications for shape, size, length, roughness, connecting junctions and ground (rim) and invert elevations. Pipe lengths were discretized into approximately equal sections. These discretized sections varied from 9 to 60 meters (30 to 200 ft). Pipe sections were assumed to be circular (equivalent diameters calculated) or rectangular. The following parameters were kept constant in pipe simulations:

- Computation time increment = 1 s.
- Manning roughness coefficient = 0.013 for new concrete, 0.015 to 0.016 for worn concrete and 0.011 for plastic
- Gate opening time in 6 to 10 s.
- Flow hydrographs at the flushing gate are assumed to increase linearly from zero to a constant flow in two seconds and also to decrease linearly from the constant rate to zero in two seconds.
- Upstream of the conduit/tank was assumed to be the input and downstream was assumed to be a free overflow.

Table 28 summarizes the hydraulic data and results from the respective flushing gates determined from the hydraulic modeling evaluations of the Cambridge facilities. The listed results are at the downstream end of the pipe or channel flushed.

Table 28. Summary of pipe flushing hydraulic modeling simulations in Cambridge, MA

Location	Flush Volume (m^3)	Flush Length (m)	Pipe Slope	Pipe Size (m)	Flow Velocity (m/s)	Flow Depth (m)
Drain Vault #1	12.1	393	0.0007	0.98, 1.37	0.39	0.06
Drain Vault #2	12.5	216	0.0009	0.98, 1.07	0.60	0.09
Drain Vault #3	12.2	220	0.0008	1.37	0.42	0.06
Drain Vault #4	13.8	343	0.001	1.22, 1.22 by 1.83	0.34	0.05
Drain Vault #5	44.6	472	0.0001	1.85 by 1.52, 1.83	0.29	0.04
Sanitary Vault #1	9.6	201	0.0003	0.46	0.50	0.08
Sanitary Vault #2	7.3	350	0.001	0.60	0.42	0.09

Interpolated EXTRAN results

Interpolated EXTRAN results for intermediate locations are noted in Table 29 through Table 35 for each flush vault. Inspection of the modeling results noted in Table 29 through Table 35 indicates that flushing velocities in excess of 0.7 m/s at the end of the flushing length are not realized. The flushing gate vendor has reviewed these results and has noted that EXTRAN does not explicitly model the "dam break" gate opening and release of flush water within vaults with floor slopes typically at 10% to 20%.

Table 29. Drain vault No.1 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	2.86	470
61	0.78	195
122	0.67	152
183	0.53	110
244	0.44	95
305	0.39	88
366	0.37	85
386	0.42	58

Note: Flush Volume = 12.1 m^3
Reach 1: Diameter = 150 mm; Length = 175 m
Reach 2: Diameter = 213 mm; Length = 210 m

Table 30. Drain vault No.2 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	3.04	628
61	1.04	210
122	0.81	165
183	0.70	122
208	0.60	95

Note: Flush Volume = 12.5 m^3
Reach 1: Diameter = 1067 mm; Length = 17 m
Reach 2: Diameter = 965 mm; Length = 191 m

Table 31. Drain vault No. 3 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	3.00	482
61	0.78	195
122	0.61	137
183	0.48	116
220	0.42	64

Note: Flush Volume = 12.2 m^3
Pipe Diameter = 213 mm; Flush Length = 220 m

Table 32. Drain vault No. 4 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	2.88	488
61	1.52	210
122	1.04	168
183	0.84	67
244	0.37	61
305	0.30	58
343	0.42	21

Note: Flush Volume = 13.8 m^3
Reach 1: Diameter = 1219 mm; Length = 175 m
Reach 2: Diameter = 1219 x 1829 mm rectangular; Length = 168 m

Table 33. Drain vault No. 5 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	3.17	851
61	0.98	366
122	0.55	198
183	0.55	168
244	0.49	140
305	0.37	122
366	0.29	116
427	0.24	107
473	0.34	43

Note: Flush Volume = 44.6 m^3
Reach 1: Diameter = 1524 x 1829 mm rectangular; Length = 76 m
Reach 2: Diameter = 1829 mm ; Length = 396 m

Table 34. Sanitary vault No. 1 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	2.78	805
61	0.73	213
122	0.62	155
183	0.56	107
201	0.51	76

Note: Flush Volume = 9.5 m^3
Pipe Diameter = 457 mm; Flush Length = 201 m

Table 35. Sanitary vault No. 2 EXTRAN results

Distance downstream (m)	Velocity (m/s)	Depth (mm)
0	2.22	457
61	1.18	152
122	0.92	128
183	0.81	113
244	0.76	95
305	0.40	104
352	0.46	58

Note: Flush Volume = 7.2 m^3
Pipe Diameter = 610 mm; Flush Length = 352 m

Alternative Sources of Flush Water

Several possible sources of flush waters and collection systems were considered in the initial design of the flushing systems.

In the initial phase of planning for the new separation system design, several hundred meters of abandoned large diameter (1–2 m or 3.3–6.6 ft) water distribution conduits were investigated for use as flushing volume collectors using inputs from nearby catch basins. These conduits would then discharge to downstream flushing gate structures. These systems were considered feasible, attractive and cost effective given the premium of space and the high cost of constructing vaults in the parkway system. These systems were not pursued as the design of major large diameter storm drains was altered, moving the need for the flushing chambers further downstream and away from the abandoned conduits.

Second, the notion of filling stormwater-flushing chambers from roof drains of the newly constructed Cambridge Water Department treatment facility was investigated in the initial phase. This concept was also abandoned, because the need for flushing chambers in this area was obviated as the major new conduits were moved further downstream.

In the final design, the notion of utilizing pumped stormwater from major drains directly into the storm flushing chambers was selected. The sanitary systems are planned to be flushed daily using pumped spent filtrate waters from the new water treatment plant.

Integration of New Conveyance System/Flushing Vaults and Grit Pit Functionalities

As shown in Figure 6, the new sewerage and drainage system piping at the intersection of Fresh Pond Parkway and Lakeview Avenue. Sanitary Vault #2 and Drain Vault #1 are also depicted in Figure 6. Pumped process (backwash) filtrate flow from the new Cambridge WTP is daily pumped into Sanitary Vault #1. This vault is filled and overflow continues 215 m down to Sanitary Vault #2. This scheme is used in lieu of an external water source to flush the sanitary trunk sewers as the City of Cambridge pays the Massachusetts Water Resources Authority for disposal of filtrate volumes. Both vaults will be flushed at least once daily. Controls at both vaults are programmed to flush in sequence once full.

During a rainfall event, stormwater from the incoming storm drain to Drain Vault #1 fills the sump adjacent to the flush chamber. Then stormwater is pumped from the sump into the flush chamber. A level sensor within the flushing volume chamber relays water level data to the PLC in the control panel which terminates pump operation when the chamber reaches a predetermined fill elevation. A level sensor in the downstream storm drain notes when the water level in down stream drain in sufficiently low to initiate the flushing operation. Activation of the hydraulic power pack then causes the flush gate to unlatch creating the flush wave. Once the system has been activated it is possible to repeat the process during a multi-peaked storm event. A generic 24-hr time clock function adds an additional level of operational flexibility. For example, it is possible to interrogate the system 24 hours after the “fist-flush” to unlatch any partially filled flush volumes. This procedure is the same for all other drain vaults.

An adjustable bottom-acting gate on the side of the entrance to the pump wet well controls the depth of storm flow entry. This feature can be used to ensure that the vault is not filled with base flows and allow bed load sediment to flow into the sump during storm events. The seven receiving grit pits (either as a manhole or integrated within the flush vault chamber) have been sized to provide maximum capture volume given the extraordinary spatial site constraints along the parkway. Average capture volume per pit is about 3 m^3. Inspection of the grit pits is programmed on a quarterly basis with clean out every two years. The flushing systems will be field tested in the summer of 2001 and will be put into operation when all upstream sewer separation work has been completed.

Equipment for each pipe flushing system includes an embedded anchoring system, frame, gate, locking and sealing mechanism, hydraulic cylinder, hydraulic tubing, hydraulic pump, reservoir, valves, mechanical connections, the electronic control panel, expansion modules, solenoids, motor, relays, timers and level sensing equipment.

Each flushing gate is fabricated of stainless steel equipped with bronze bushings for the hinges and locking mechanism. The gate is fixed to the flushing chamber wall stainless steel anchors. The flushing gate hinge mechanism is designed to allow for full travel and permit manual lifting of gate flap to a minimum of 135^0 from the vertical plane (when the gate is fully closed). The hinges are adjustable in two directions. Material for hinges and the locking mechanism is stainless steel and bronze.

A hydraulic power pack is located in the control panel for each flushing gate. Hydraulic pressure is not used to lock the gates or to keep the gates closed. The hydraulic cylinder requires no more than 200 psi to release or open the locking mechanism. There is only one hydraulic cylinder and one hydraulic line for each gate. The hydraulic cylinder is constructed of stainless steel. There is no sealing material inside or in the operating shaft. The hydraulic cylinder has no mechanical or friction seals, no piston rings or sealed shaft. The cylinder is sealed and is leak proof.

There is one manually operated control panel, equipped with a selector switch for LOCAL/OFF/REMOTE operation. In LOCAL (manual) mode any of the flushing gates linked can be flushed from the hydraulic power pack/control panel. In REMOTE mode, a contact closure is the signal to open the flush gate. Water level indicators are explosion-proof, continuous, flexible, level transmitter type. These devices control the operation of the flushing system. Water level indicators are located in the flushing volume chamber and in the downstream pipe to note chamber fill level and the downstream pipe water level. Each level probe is equipped with a stilling well to protect it from physical damage.

Each control panel controls the local (manual) flushing of the system from a series of cabinet face mounted pushbuttons and selector switches. Each is equipped with a PLC and a three-position selector switch, which will allow for LOCAL/OFF/REMOTE operation. Each control panel enclosure houses controls for the hydraulic equipment and for all of the electronic components. A second enclosure within the first separates the electronic components from the hydraulic ones. All operational status alarms are manually reset and both alarms and status lights have dry contacts for future SCADA system connection. Each control panel allows for manual operation (pushbutton) of the flushing system, so that any of the flush ways may be flushed at random. Once a flush is started the control panel cannot accept another signal, other than abort, until the flush is completed. It is equipped with a status light indicating which flushing gate is operating. The panel is also equipped with indicator lights to show if high water level conditions exist in the storage areas. The PLC is used to control the duration of the flush by using various internal timers and relays and by taking the water level in the sump into consideration.

Drain Vaults and Sanitary Vaults
Table 36 presents the design aspects and functions of each of the flush vaults.

Table 36. Flushing vault functions

Flush Vault	Flushing Function	Grit Collection Location	In-line Grit Collector	Flush Water Source	Flush Water Pre-treated	Flushing Vault Used as Junction Structure
Drain Vault #1	Yes	DV # 3	No	Stormwater(1)	No	No
Drain Vault #2	Yes	D/S Grit Manhole	Yes	Stormwater(2)	No	Yes
Drain Vault #3	Yes	DV # 5	No	Stormwater(2)	No	Yes
Drain Vault #4	Yes	D/S Grit Manhole	No	Stormwater(2)	No	Yes
Drain Vault #5	Yes	D/S Grit Manhole	No	Stormwater(2)	No	Yes
Sanitary Vault #1	Yes	N/A	No	WTP	Yes(4)	Yes
Sanitary Vault #2	Yes	N/A	No	WTP	Yes	Yes

Notes:
1. Pumped from local storm drain system manhole.
2. Pumped at vault.
3. Pumped Water Treatment Plant (WTP) filtrate.
4. Vortex separator used to pretreat pumped flow from the WTP by removing heavy grit from being conveyed by gravity from SV #1 to SV #2.

Operation and Maintenance
In order to maintain effective system operation, routine scheduled maintenance must be performed. Maintenance procedures for the flush vaults and grit pits are presented below.

Flushing Vaults
A typical flushing gate vault maintenance procedure is outlined below.

Task 1: Check flushing gates including electrical: Each flushing gate vault should be visually inspected on a monthly basis. The consistent operation of these devices will ensure that the full capacity of the storm drain is available during the course of a wet weather event. The inspection should include verification of proper operation of flushing equipment as well as sensing instrumentation and other electrical equipment.

This task requires two personnel over the course of two hours, as these structures are typically located in traffic sensitive areas. All equipment operation can be visually verified from the surface and confined space entry procedures are not required to perform this task.

Task 2: Check instrumentation/controls: Instrumentation and controls will be inspected on a quarterly basis. The inspection will provide a more detailed analysis of the operation of the flushing vaults. The flushing vault will be manually activated, as controls and electrical equipment are monitored. This will provide a direct indication of the status and operation of the equipment.

This task requires two personnel over the course of two hours as these structures are located in traffic sensitive areas. All equipment operation can be visually verified from the surface and confined space entry procedures are not required to perform this task.

Task 3: Clean pump wet well: Each pump wet well should be cleaned on an annual basis. During the operation of the wet well pumping units debris and detritus will remain as they are entrained within the source. The debris is left behind as part of the function of the wet well pumping system. The debris will gradually accumulate and impede the operation of the equipment. The debris and detritus should be removed from the pump wet well on an annual basis to allow minimize odors from entrained organic materials and as part of preventative maintenance. This task requires three personnel over the course of four hours as these structures are considered confined spaces and require set-up and breakdown time to perform adequate cleaning of these facilities. Cleaning will also require the services of external water supplies and pipe cleaning devices. Table 37 summarizes the annual labor requirements for operation and maintenance of the flushing gates.

Table 37. Flushing gate vault annual labor requirements

Task	Crew Size	Time (h)	Labor/event (man-h)	Frequency (times/yr)	Annual Labor (man-h)
1	2	2	4	12	48
2	2	2	4	4	16
3	3	4	12	1	12

Grit Pits

Grit pits operate passively by removing heavy entrained matter from the stormwater by reducing the velocity and allowing settling to occur. Failure to remove the collected materials will reduce the efficiency of the devices and cause the grit to settle in the drain pipes reducing the capacity of the drains. Cleaning will ensure continued operation and reduced maintenance costs over the equipment life-span. Cleaning will require the use of vactor-type truck and an outside water source as well as the disposal of collected residuals.

This task requires three personnel and confined space entry procedures depending on the size and configuration of the grit pit. Table 38 summarizes the annual labor requirements for operation and maintenance of the grit pits (either a manhole or a sump integrated in a flush vault chamber).

Table 38. Grit pit annual labor requirements

Task	Crew Size	Time (h)	Labor/event (man-h)	Frequency (times/yr)	Annual Labor (man-h)
1	3	3.5	10.5	2	21

Sediment Accumulation and Estimating Methodology

The first step in estimating maintenance requirements for a collection system is to characterize the sediments in the system. The process will determine the characteristics and quantity of material that is anticipated to settle within the collection system that will need to be flushed.

Stormwater Runoff Solids Characteristics

The Construction Industry Research and Information Association (CIRIA) in the United Kingdom (UK) characterizes medium strength stormwater as containing 300 mg/L SS load (particles < 200 μm (transported in suspension) and 50 mg/L grit (particles > 250 μm moving as bed load). These are average values from UK urbanized areas, serviced by catchbasins with little sump volume, with nominal street cleaning. The National Urban Runoff Program (NURP) reports a median SS value of 180 mg/L (range of median values from 141 mg/L to 224 mg/L) developed from long term measurements in 21 urbanized catchments (9 across the US). It is important to note that none of the NURP measurement programs in the early 1980s sampled bed-load as this is extremely difficult to accomplish in practice. European sewer solids research initiatives in the 1990s noted the importance of the particle size distribution. Pisano and Brombach (1996) reported the results of several hundred solids settling curves for a wide variety of waste types (dry weather flow, CSO, storm water, street solids, sediment scraping, pipe slime) collected across North America and Germany over the last two decades.

Using this collective body of information, an assumed mass solids distribution of stormwater solids including both grit and lighter particles is considered. The distribution is presented in Table 39. Settling velocities noted reflect worn angular particles at 10 degrees Celsius. Inspection of Table 39 indicates that the greatest preponderance of materials is associated with solids particles in the 16–62 μm range associated with settling velocities between 0.02 to 0.25 cm/s (0.008 to 0.1 in./s). As a matter of note, mass settling velocities determined from most settling column tests of stormwater, which have excluded bed-load materials, are generally within the lower end of the range noted above. An overall SS concentration, including grit and suspended load, equal to 300 mg/L is assumed for the heavily urbanized catchment tributary to the Fresh Pond Parkway system.

Table 39. Assumed stormwater runoff solids characteristics

Category	Size (μm)	Settling Velocity (cm/s)	% mass per category
Very fine gravel	> 2000	30.0	1
Very coarse sand	> 1000	15.0	2
Coarse sand	> 500	7.0	4
Medium sand	> 250	2.8	5
Fine sand	> 125	1.0	14
Very fine sand	> 62	.25	20
Coarse silt	> 31	.06	26
Medium silt	> 16	.02	18
Fine silt	> 8	.01	6
Very fine silt	> 4	.005	2
			Sum = 100

Next, solids removal associated with a comprehensive, closely spaced system of catch basins and fairly rigorous street sweeping program within the area are included to reduce the above assumed distribution of stormwater solids). In most areas of Cambridge the rule is generally about one catch basin per 1.5 acres. Typically, street sweeping (mechanical) occurs within the Fresh Pond Parkway catchment about 12–15 times per yr.

Measured NURP results indicate on the average, 15% to 20% SS reductions for urbanized areas occur when street sweeping is routinely practiced. Ashley (1992) reported European results noting solids removal per solids sizes for mechanical type street sweeping. His results have been generalized to fit within the 10 particle sizes noted in Table 40 and are given below.

Table 40. Solids removal per solids size for mechanical street sweeping

Particle Size (μm)	Effectiveness (%)
>2000	80
>1000	70
>500	60
>250	55
>125	45
>62	30
>31	15
Otherwise zero	

Pitt (1984) measured the solids removal effectiveness of 100 catch basins and concluded that solids removal is principally a function of the rate of incoming gutter flow. Removal rates approach 45% when the inflow is discharging less than 0.05 cfs and is negligible for flow rates in excess of 1.5 cfs. Using judgment and research and development experience with catch basin performance conducted in Dorchester by Process Research (1976), Pitt's results are generalized in Table 41 to fit into the overall conceptual solids distribution scheme used so far.

Table 41. Solids removal per solids size for typical Cambridge urban catchment area

Particle Size (μm)	Effectiveness (%)
>2000	100
>1000	90
>500	80
>250	60
>125	40
>62	20
>31	10
Otherwise zero	

Using the above formulations, the initial assumed solids distribution of stormwater into the catchment is reduced to reflect the collective impacts of the surface-related Best Management Practices (BMP's). The final average SS concentration after this reduction is 145 mg/L that falls within the range of NURP reported values but higher than CIRA assumptions for clean stormwater that is 60 mg/L. Removal associated with catch basin programs is 23% while street sweeping accounts for an overall reduction of 18%. Table 42 shows the characteristics of stowmwater runoff solids in Cambridge, Massachusetts. The median settling velocity noted in the "final" mass solids distribution in Table 42 is 0.06 cm/s which is consistent with measured stormwater values.

Table 42. Stormwater runoff solids characteristics in Cambridge, MA urban catchment

Category	Size (μm)	Settling Velocity (cm/s)	Initial / (Final) (% mass per category)
Very fine gravel	> 2000	30.0	1 / (0.0)
Very coarse sand	> 1000	15.0	2 / (0.1)
Coarse sand	> 500	7.0	4 / (0 .3)
Medium sand	> 250	2.8	5 / (0.9)
Fine sand	> 125	1.0	14 / (4.6)
Very fine sand	> 62	.25	20 / (11.2)
Coarse silt	> 31	.06	26 / (19.9)
Medium silt	> 16	.02	18 / (18.)
Fine silt	> 8	.01	6 / (6)
Very fine silt	> 4	.005	2 / (2)
			Sum = 100 / (63.0)
Initial SS = 300ml/L; Final SS = 145 mg/L			

Runoff Volumes

Average annual runoff volumes for the catchment are computed assuming a total of 1000 mm (3.28 ft) of rainfall per yr and 75% conversion to runoff. The annual volume of runoff for the Fresh Pond Parkway catchment (100-ha or 250 acre) is approximately 822,000 kL (217 Mgal).

Potential Wet Weather Solids Deposition

The mass of annual solids deposition within the Fresh Pond Parkway catchment is estimated as follows. Assuming quiescent settling with an average forward flow velocity of 0.3 m/s (1 ft/s), all particles having settling velocity greater than 0.06 cm/s (0.02 in./s) are expected to deposit. Table 42 indicates that the mass concentration of particles having settling velocities less than 0.06 cm/s (0.02 in./s) equals 78 mg/L. The difference between the final average SS concentration (145 mg/L) and the mass concentration of particles with settling velocities less than 0.06 cm/s (0.02 in./s) will settle in the storm pipes. This equals 67 mg/L. Annual solids' depositions in the Fresh Pond Parkway storm drain system resulting from stormwater inputs are shown in Table 43 below. Estimates for the annual deposited masses equal the total runoff volume times the concentration of deposited materials above.

Table 43. Annual solids deposition in the fresh pond parkway system

Runoff Volume (kL)	Mass Concentration (mg/L) (Particles less than 0.06 cm/s)	Annual Solids Deposition (kg)
822,000	67	55,000

Bulk specific weights of such fine-grained sediments have been noted by the Construction Industry Research and Information Association (CIRA) to be 1602 kg/m^3 (100 lb/ft^3). This specific weight does not reflect any waterlogged materials that may be entrapped within the sediments. Floatables and trash generated within the entire catchment will be inordinately high due to the large preponderance of eating establishments, hotels and malls. While the catch basins in the area will capture much of this material, some material will invariably escape from the catch basins into the storm drain system. Much of this material will become water logged and sink due to the very low forward outflow conditions. To account for this, the bulk specific weight is reduced to 1,250 kg/m^3 (85 lb/ft^3). On an annual basis, the seven grit pits will be cleaned twice.

Cost Analysis

Operation and Maintenance Costs

This section includes the basis for estimates of annual utility costs, preventive maintenance, parts replacement and structural repairs as needed.

Annual operation and maintenance (O&M) cost estimates are summarized in Table 44. The costs are developed from the stormwater management system operation and maintenance recommendations. The actual costs for O&M are dependent on the amount of operational equipment in service at any given time. The cost estimates are based on the labor estimates presented in Tables 37 and 38 annual labor requirements for flushing gate vault and grit pit, respectively.

The unit costs are based upon the number of man hours estimated to perform the given task plus the cost of specialized equipment for cleaning as well as the facility operation and maintenance cost including electrical, structural and mechanical upkeep and repair. The rates include overhead and equipment necessary to perform the required tasks (i.e., maintenance staff at $75/man-h and vactor/flusher truck at $120/h).

Table 44. Annual operation and maintenance cost estimates

Task	**Annual Unit Cost**
Flushing Vaults - Inspection	$3,600
Flushing Vaults - Check Controls	$1,200
Flushing Vaults - Clean	$1,380
Flushing Vaults - Electrical, Mechanical & Structural	$1,000
Grit Pits - Clean	$2,400

Cost Effectiveness Analysis of Automated Flushing versus Periodic Manual Sediment Removal

This analysis presents life cycle costs for two alternative systems to clean the major storm and sanitary systems described above over a thirty-year period. Catch basin cleaning and cleaning of all incidental lateral lines tributary to both systems were not included. The cost of each alternative system does not include estimates of materials to be removed and disposed. Notwithstanding this limitation, all costs necessary to remove deposits to street level using either scheme are included. Assumptions for the cost analysis of both alternatives are listed below:

1. Pipe cleaning costs assume inflation rate of 3.12% per yr.
2. Stormwater pipes are cleaned every 5 yrs, and sanitary pipes are cleaned every 3 yrs.
3. Flushing costs are based on inflation rate of 3.12% per yr and discount rate of 7.1% per yr.
4. Discount Period = 30 yrs.
5. Maintenance labor cost = $75/man-hr.
6. Sanitary systems will be flushed daily using spent process water from the water treatment plant.
7. Storm systems will be flushed approximately every two weeks depending on rainfall.

Capital costs for the flushing facilities reflect final construction costs with all change orders, and include excavation and backfill, hauling, pavement, gravel, dewatering, hazardous soil disposal, piping, traffic maintenance, equipment, structures and mobilization. Since the flushing facilities have been built at piping system intersection points, total facility construction costs have been adjusted to only include flushing and grit capture functions.

Grit pits have been included for the storm systems only. Pit volumes average about 3 m^3 (793 gal). Small diameter 75 mm-100 mm (3-4 in.) force mains from the Cambridge Water Treatment plant to the sanitary flushing systems are included in the capital cost estimates. Operation and maintenance costs for flushing sites include hydraulic oil, routine inspection and servicing, power, and removal of collected sediments from the storm system vaults on a semi-annual basis. Trucking and disposal costs are not included.

Capital Costs for the Automated Flushing Systems

The capital costs of the flushing systems include the flushing vaults, the grit sumps/manholes (storm only), small above ground vaults to house the hydraulic power pack units to trigger the flushing systems and electrical pumping controls, and chambers as appropriate to pump storm water into the flushing chambers.

No additional sewage treatment costs associated with added " flush water" is included for the two sanitary sewer chambers at Fresh Pond Circle as this volume. It is already paid for as spent filtrate from the City of Cambridge new water treatment plant. No such costs are included for the storm system, as collected stormwater will be used to flush the storm drain pipes. Incidental costs of pumping storm water to flushing vaults are included. It is assumed that on a quarterly basis all vaults will be cleaned of collected materials. Trucking and disposal costs are not included. Pertinent cost summary details of the flushing systems are given in Table 45 and Table 46.

Table 45. Flushing system capital costs (ENR Construction Cost Index = 6389, August 2001)

Location	Gross Construction Cost ($)	Apportioned Flushing System Cost ($)
Drain Vault #1	210,000	170,000
Drain Vault #2	290,000	240,000
Drain Vault #3	325,000	265,000
Drain Vault #4	335,000	275,000
Drain Vault #5	771,000	661,000
Downstream DV#5 Grit Pit	N/A	80,000
Sanitary Vault #1	187,000	147,000
Sanitary Vault #2	158,000	132,000
Force Mains for Sanitary Vaults	N/A	82,000
Totals	2,276,000	2,052,000

Table 46. Flushing system operation and maintenance costs

Flushing System	Average Annual Cost ($)	Present Value Cost ($)
Storm Drain	17,600	1,475,000
Sanitary	7,040	236,000
Total	24,640	1,711,000

The overall present worth cost including capital and operation and maintenance costs over a 30 year period for the automatic storm and sanitary sewer flushing systems is estimated to equal $3,766,000. Average capital cost of flushing volume is approximately $18,000/m^3.

Costs for Manual Cleaning

It is assumed that the sanitary systems will be cleaned on a three-year cycle and the storm lines cleaned on a five-year cycle. Unit cleaning costs were obtained from actual contractor bids for the cleaning construction package of existing storm and sanitary sewers within the project area and then used to estimate cleaning of all newly constructed and rehabilitated pipes as follows:

1. 1067 mm (42 in.) Storm Drain -$102.00/m ($34.00/ft)
2. 1219 mm (48in.) Storm Drain -$129.00/m ($43.00/ft)
3. 1372 mm (54 in.) Storm Drain -$163.50/m ($54.50/ft)
4. 1829 mm (72 in.) Storm Drain- $267.00/m ($89.00/ft)
5. 1.22 m x 1.83 m (4 ft by 6 ft) Storm Drain -$232.50/m ($77.50/ft)
6. 1.85m by1.52 m (5 ft by 6 ft) Storm Drain - $312/m ($96.00/ft)
7. 457 mm (18 in.) - 610mm (24 in.) Sanitary -$49.50/m ($15.00/ft)
8. Storm Sewer Cleaning Mobilization $55,000
9. Sanitary Sewer Cleaning Mobilization $5,000

Present worth costs for cleaning the storm drain system at 5-yr intervals for a 30-yr period equals $4,692,000. Similarly, the present worth cost for manually cleaning the sanitary sewer system at 3-year intervals equals $920,000. Total present worth costs for the 30-yr period equals $5,612,000. No trucking and sediment disposal costs for either alternative are assumed. On a life cycle basis, the automated flushing scheme is more cost effective than periodic manual cleaning with savings of $1,850,000. The reader must also be aware that the avoidance of potential real and societal costs of flooding caused by surcharged and clogged drains and sewers is not reflected in this cost estimate. In addition, the nuisance level costs associated with traffic disruption on Fresh Pond Parkway (4 lanes with 50,000 vehicles per day) are also not reflected.